Conf-920430--32

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CONF-920430--32

DE92 005420

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For presentation and publishing in proceedings of 1992 International High Level Waste Management Conference, Las Vegas, NV, April 12-16, 1991

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managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U. S. DEPARTMENT OF ENERGY
under contract
DE-AC05-84OR21400

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ABSTRACT

This paper discusses the feasibility of adapting concepts and tools that were developed for the U.S. military's transportation management systems to the management of the Federal Waste Management System's (FWMS) Transportation System. Many of the lessons learned in the development of the planning and scheduling software for the U.S. military are applicable to the development of similar software for the FWMS Transportation System. The resulting system would be invaluable to the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM), both initially, for long-range planning, and later, in day-to-day scheduling and management activities.

I. INTRODUCTION

OCRWM is currently developing an FWMS Transportation System to ship the spent nuclear fuel from more than 120 utility-owned commercial reactors at 76 different sites to a temporary storage and/or a permanent geologic disposal facility. A system as large and complicated as the one envisioned by OCRWM in scheduling and implementing as many as 250 rail and 725 truck shipments of spent nuclear fuel from a significant number of the 76 sites annually could benefit from a sophisticated system for scheduling and managing such shipments. Since the transportation system may also ultimately be called upon to ship high-level waste and research reactor fuel from a significant number of additional sites to the disposal facility, the need for this capability will increase with time.

A number of new automated planning, scheduling, and analysis software tools were developed in the late 1980s and early 1990s for the U.S. Armed Forces Transportation Component Commands. These tools, which have replaced manual or less automated systems that were previously in use, have significantly improved the timeliness and efficiency of U.S. Armed Forces transportation activities, which are coordinated by the U.S Transportation Command (USTRANSCOM). The FWMS Transportation System for spent nuclear fuel and high-level waste will have much of the same basic structure as that of the Armed Forces Transportation

Component Commands. Much of the work that has been done in the development of the automated systems for the military could be applied to OCRWM's problem of coordinating the shipment of spent nuclear fuel and high-level radioactive waste.

This paper discusses the potential applicability to the FWMS Transportation System of the automated planning and scheduling software systems that have been developed for U.S. military forces. Section II briefly introduces the military planning and scheduling systems that have been (and continues to be) developed. Section III outlines the characteristics of the FWMS Transportation System. Section IV describes the airlift software system (ADANS) and compares its features with those envisioned as needed by a similar set of software which could be utilized for the FWMS Transportation System. Section V outlines the software development process that would be required to implement the system for the FWMS Transportation System. Section VI summarizes lessons learned from the development of the military scheduling systems and discusses how they could be applied to a system developed for the FWMS Transportation System.

II. MILITARY PLANNING AND SCHEDULING SYSTEMS

Under USTRANSCOM, each of the three major branches of the U.S. Armed Forces has a Transportation Component Command. The Army coordinates land movements inside the continental United States with the Military Traffic Management Command (MTMC). The Navy organizes sealift under the Military Sealift Command (MSC). The Air Force's Military Airlift Command (MAC) airlifts passengers and cargo around the world. The automated systems developed for each of these commands have made planning and scheduling for peacetime, exercise, and wartime missions much more efficient.

The global coordination of the military movements performed by USTRANSCOM is accomplished using the Flow and Analysis System for TRANSCOM (FAST) software, which analyzes cargo and passenger movement requirements and assigns responsibility for the movement of these requirements to one of the Component Commands.[1] FAST was installed at USTRANSCOM headquarters and area commands in 1991.

MTMC uses the Strategic Deployment System (STRADS) software to plan the ground movement of cargo and passengers from their bases to airfields and seaports.[2] STRADS had initial operating capability by the end of 1991 and will be fully operational at MTMC headquarters and the four area commands by the end of 1992.

MSC uses the Scheduling Algorithm for Improving Lift (SAIL) software for assessing and planning sealift movements.[3] MSC did a final evaluation of the SAIL algorithm in late 1991; it will be in use in early 1992. The SAIL algorithm was also used actively by USTRANSCOM during Operation Desert Storm as a module of FAST.

MAC uses the Airlift Deployment Analysis System (ADANS) software for the scheduling airlift movements for both passengers and cargo.[4] Several different planning and scheduling modules of ADANS have been implemented since 1989, including the MAC execution airlift mission scheduling software, which was expeditiously developed for Operation Desert Storm. This software system will be considered here for comparing its features with those needed by a system for managing the FWMS Transportation System.

The military's automated scheduling systems are implemented on a variety of hardware ranging from personal computers, such as FAST and STRADS, to Workstation-based systems linked by local area networks, such as ADANS to SAIL on both personal computers and mainframes. They use a database management system and mathematical algorithms for scheduling passengers and cargo on a limited set of transportation resources so that they can be moved over a network from an origin to a destination within a specific time frame. These scheduling systems can also be used to adjust schedules when unplanned events such as the following occur: changes in equipment availability; delays in delivery of items to be moved; in-transit delays caused by weather or mechanical failures; and closure of land, sea, or air ports.

III. THE FEDERAL WASTE MANAGEMENT SYSTEM TRANSPORTATION SYSTEM

The FWMS Transportation System is being developed to plan, schedule, and provide the transportation of spent nuclear fuel and high-level radioactive waste from generating sites (nuclear power plants) and temporary storage sites to intermediate storage and permanent repository sites. Currently, there appear to be no plans to develop automated tools to plan, schedule, or manage the transportation of such materials.

The FWMS Transportation System will be complex and will require multimodal transportation planning. The system must manage the waste, a fleet of casks and its associated ancillary equipment and transporters, and the operators of vehicles, all of which interface with a large number of shipping sites. It must recognize and comply with the legal limitations imposed by federal, state, and Indian tribe authorities. In addition, it must integrate the Monitored Retrievable Storage (MRS) facility, a Cask Maintenance Facility, and a permanent geologic disposal facility into the planning and scheduling of the shipments. Finally, it must constantly track vehicles, other equipment, and operating personnel to facilitate the proper planning and scheduling of shipments.

Numerous problems confront those who intend to manage this task: more than 120 unique facilities; approximately 100 shipping casks with multiple characteristics; three modes of transport (truck, rail and barge) involving some intermodal transfer operations; and shifting demands that result from the exchange of shipping rights between utilities, possible changing schedules to account for inconsistencies in operating schedules, equipment failures, changing demands placed on delivery schedules by the facilities involved, and inclement weather. These factors will add to the complexity of the problem. The system must be able to continuously receive information about the radioactive materials to be shipped, as well as the transportation resources, and then to develop and adjust schedules honoring all the constraints.

From the transportation analyst's viewpoint, the problem is complex because the casks containing the spent fuel will be moved by truck, rail, and barge - three modes of transport that are typically scheduled independently, are contracted for separately, utilize different pieces of operating equipment, and use different management and operating techniques. The casks must be delivered to, picked up from, and routed between various facilities. Some will be controlled by the DOE, while most will be controlled by individual utility companies; and all of them will be subject to variations in throughput rates that will be outside of the control of the FWMS Transportation System. All of these activities must be coupled with appropriate testing and maintenance of the casks to retain U.S. Nuclear Regulatory Commission certification. Thus, the cask management problem specifically, and the FWMS Transportation System generally, is inexorably linked to the scheduling problem. Multiple stops at FWMS facilities (i.e., the MRS facility, the repository, and a Cask Maintenance Facility) increase the complexity by requiring coordination within and between these facilities as well as the reactor/waste producing sites. An FWMS Transportation System planning/scheduling/management tool would assist in providing a consistent flow of materials through these facilities which, in turn would allow the DOE to operate them more economically and with greater assurance of control and safety.

The FWMS Transportation System, as currently envisioned, will consist of five subsystems:[5]

1) the Cask Subsystem;
2) the Field Operations Subsystem;
3) the Carriage Subsystem;
4) the Servicing and Maintenance Subsystem; and
5) the Planning and Control Subsystem.

Each of these subsystems will need to have components involving equipment, such as casks, associated ancillary equipment, and transport vehicles; facilities, such as a Cask Maintenance Facility and an Operational Control Center; personnel, such as traffic managers, field operations representatives for overseeing cask loading and handling at shipping/receiving sites, and training staff; and software, such as procedures, maintenance records, and computer codes.

The development of individual elements of and tools for the FWMS Transportation System has already begun. For example, the functions of and a system description of the FWMS Transportation System are being developed,[6] simulation models of the FWMS Transportation System have been developed,[7] descriptions of the shipping capabilities and transportation access for originating sites are being developed,[8,9] and database information on the spent fuel to be shipped exists.[10,11] Casks for the highway, railway, and waterway carriage of the spent fuel are being designed.[12] These various elements could be integrated into a computer-based planning, scheduling, and management system much like those that have already been developed for similar transportation system management needs encountered by the U.S. Armed Forces Transportation Component Commands.

IV. SIMILARITIES BETWEEN THE FWMS TRANSPORTATION SYSTEM AND THE MILITARY TRANSPORTATION PROBLEM

There are many similarities between the requirements of a military transportation system and those of the FWMS Transportation System. MAC's airlift scheduling system, ADANS, will be used as an example to show the similarities in scheduling and to determine the extent to which the technology that has been developed is transferrable.

The MAC airlift system consists of six major components (subsystems) that can be compared with the five subsystems of the FWMS Transportation System discussed in Section III. These are:

(1) the aircraft,
(2) the airfield resources,
(3) the airlift network,
(4) the air crews,
(5) the cargo and passengers, and
(6) the command and control actions.

Table 1 provides a top-level comparison of the basic components of MAC's transportation system with those expected in the FWMS Transportation System. Table 1 demonstrates that, although the elements are different in nature, the same basic elements are involved (locations, routes, equipment, cargo, and personnel); and this could lead to an effective transfer of the ADANS technology to the FWMS for managing the FWMS Transportation System. There are direct comparisons, for example between the equipment involved (aircraft versus casks and associated hardware; airfields versus shipping and receiving sites; etc.), where much of the logic for managing this equipment could be readily adapted from ADANS to an FWMS Transportation Deployment Analysis System.

With the ADANS software, schedules are seen in a time and spatial context. The major considerations in terms of time for airlift schedulers are the (1) available-to-load date, (2) earliest arrival date, and (3) latest arrival date. The goal of the airlift scheduler is to pick up the cargo after the "available-to-load date" at the origin airfield and deliver it within the window established by the "earliest arrival" and the "latest arrival" dates to the destination. Within this time frame, the aircraft will move through a series of stops to execute the mission.

A typical MAC airlift mission involves many of the same types of actions and decisions that will be faced by the manager of the FWMS Transportation System. In Table 2, a typical airlift mission is compared with a typical envisioned FWMS Transportation System shipment (i.e., in both cases, for a single carriage of cargo from the originating site to the destination). As Table 2 illustrates, it parallels, in many respects, the details that will be entailed in the shipment of spent fuel and/or high-level waste from a generating site to the MRS facility or a repository. Each airlift component plays an integral role in the scheduling process of airlift; in a similar fashion, each has a counterpart in the FWMS Transportation System.

Scheduling for the airlift system is done at a central command headquarters (component 6 above), using the MAC resources (components 1-4 above) to schedule the cargo and passengers (component 5 above). The command and control actions then affect the mission as it is being executed and may result in changes in the mission as it is being flown. For the FWMS Transportation System, the Operations Control Center envisioned as being part of the Planning and Control Subsystem will utilize the FWMS Transportation System resources (Cask, Carriage, Field Operations, and Servicing and Maintenance Subsystems) to schedule the "cargo" (the spent nuclear fuel or high-level radioactive waste) to be shipped.

With MAC, the vehicles used to move the cargo are aircraft (C130, C141, C5, and civilian aircraft). The FWMS Transportation System has an equivalent set of vehicle resources in the form of the trucks, railcars, and barges and the associated casks that will be needed to move the spent fuel and high-level radioactive waste from the generating sites to a permanent repository or MRS facility. The principle is the same for both systems, although different vehicles hold various amounts of cargo, depending on the capacity of the vehicle. The major concerns about the aircraft are its capacity (weight or volume) and range. The major concerns about the vehicles in the FWMS Transportation System are their capacity (weight or volume), radiation level emitted from the cask, and range.

The airfield resources component consists of aircraft permissions at the airfield to land and refuel; it also involves the capacity of the airfield to handle a specific number of airplanes. This upper bound on the maximum number of aircraft, called the maximum on ground (MOG), is used as a surrogate for runway capacity, parking capacity, and personnel and equipment on the ground to onload and offload the aircraft. The time of airfield operation is also considered under this category. The airfield resources component sets a limit on the throughput of cargo at a given airfield. Aircraft maintenance is also an important function that is performed at the home-station airfield. After the aircraft flies a specified number of hours, it must return to its home station for maintenance servicing. The FWMS Transportation System has an equivalent to airfields. The reactor sites, receiving sites, Cask Maintenance Facility, in-transit stopping points, intermodal transfer points, and emergency response centers have similar constraints to those of the airfields. Each of these facilities will have specific permissible activities that can take place there. They will certainly have modal limitations and a capacity limit to handle certain types of casks (i.e., truck or rail). Personnel at these facilities will be limited to specific work times and exposure rates to radiation. These limitations, of course, will affect the throughput of the spent fuel at each of the facilities. Emergency response centers would not be involved with everyday operation of the FWMS Transportation System, but their resources would be available to mitigate any emergency that might occur involving a vehicle or cask in the system. Rapid access to the emergency response resource information for any location along the route is essential for the safe operation of the FWMS Transportation System.

The structure of the airlift network is somewhat simpler than that of the FWMS Transportation System. MAC only uses one mode to deliver its cargo. The FWMS Transportation System will potentially use three modes (highway, rail, and barge) to ship the spent fuel and high-level radioactive waste from reactors to a storage site. This shipment process may also involve intermodal transfers, such as truck to rail or barge to rail. This adds a further degree of complexity to the scheduling problem. The utility will make the final determination on the initial mode of shipment, but a major determining factor in this decision will be the accessibility to the plant by rail and water transport.

Aircrews fly the missions. The complexity of the airlift system is equivalent to that of the FWMS Transportation System. Each crew only flies a specific type of aircraft (C130, C141, C5, or civilian aircraft). Crew members are limited to a preset number of operating hours to fly the aircraft. After that, they must rest a specified length of time before flying again. The same is true with the crews that will be operating the vehicles that carry the spent nuclear fuel and high-level waste. Crews for trucks will also be limited on operating time, while railroad crews will periodically change during these shipments. Federal regulations for truck crews set the limits for the time an individual can operate the vehicle as well as the exposure limits resulting from the radiation emitted from the cask.

Airlift carries both cargo and passengers. The cargo must be compatible with the aircraft and the other types of cargo and/or passengers on the aircraft. For instance, there are certain prohibitions on carrying hazardous materials with other cargo or passengers. Similarly, specific restrictions will be placed on the numbers, types, and characteristics of the fuel assemblies loaded in each cask. These include the age of the fuel, type of fuel (BWR or PWR), enrichment, burnup, and status (failed or not failed).

Once schedules have been developed, there is no guarantee that they will be executed as planned. Frequently, circumstances that are unforseen (e.g., priority changes, resource available, mechanical problems, and weather conditions) will cause a deviation in the schedule. The same types of circumstances are projected to result in changes to schedules developed in the FWMS Transportation System. It is essential to have an efficient Command and Control system to monitor the status of the shipments and resources so that any changes in the schedules and availability of resources can be dealt with as safely and efficiently as possible.

The above discussion illustrates that there are many similarities between the scheduling system for the currently operating MAC airlift and that of the planned FWMS Transportation

System. Development of the scheduling system to make it applicable to the FWMS Transportation System would require implementing a database with currently available information, development of a database management system, and a set of scheduling algorithms and analysis tools to provide the users with tools to build schedules and evaluate them. Available data that could be used include information on transportation resources, transportation network and facilities, and spent fuel characteristics. Current information resources include the Transportation System Database (TSDB), Characteristics Database (CDB), Facility Interface Capability Assessment (FICA), results from the Near Site Transportation Infrastructure Study (NSTI), follow-on assessments arising from the FICA and NSTI work that will define specific-site modal and near-site intermodal capabilities, equipment data and procedures, operating procedures, personnel exposure data, Standard Contract Information (i.e., data from commitments made between the DOE and the Purchasers via 10 CFR 961), emergency response information, transporter repair information, FWMS facilities data as they develop, and real-time tracking data. The output of the system would consist of schedules for campaigns, FWMS facilities, equipment, and operations personnel.

V. THE SOFTWARE DEVELOPMENT PROCESS

Operation of the FWMS Transportation System will be very complicated, requiring a high degree of planning and automation. The development of these capabilities is expected to require a long lead time.

As stated previously, the initial planning for the military transportation systems began in the mid-1980s. Most of the systems are just now coming online for use in actual operations. It is not uncommon for software systems that plan and schedule complex transportation systems to require 5 to 6 years of development. One major advantage for the DOE is that much of the initial groundwork for the software development of these systems has been done through these military research projects.

The development of an automated scheduling system involves a number of important steps that must be taken to lead to a useful end product. First, one of the most important steps is the definition of requirements. This step involves working with the users to determine their needs. The development of prototypes that can be used to familiarize the users with the features of the system is a useful strategy in helping the users to determine what they need. It also enables users to project the needs of and the expanded possibilities for an automated system.

Once the requirements have been determined, a system design team develops a high-level design for the database and software. Hardware decisions should also be made at this time.

Finally, the detailed design and actual development of the software begin. Integrated with the software development is a series of user reviews during development to ensure that the needs of the users are being met. Any change in direction resulting from these reviews requires a reevaluation of the requirements and design. Delivery of the software occurs when user requirements are met. The maintenance phase begins after the delivery of the software, which may involve solving software problems, modifying the software, or making major changes to add capability or enhancements. As the system evolves from a planning tool to one used in everyday scheduling, the requirements for the system will change and functionality may need to be added.

VI. LESSONS LEARNED FROM THE DEVELOPMENT OF MILITARY SCHEDULING SYSTEMS

The development of useful software systems for scheduling is a complex and time-consuming process. One of the most important things that the developers and users must do is to educate one another. Each developer must gain a thorough knowledge of the user requirements. It is up to the developer to understand what the job entails and how to improve the system for the user. The user has the responsibility for helping the developer learn about his job and evaluating the new system to determine whether it has the requested desired features. Communications must work both ways in order to achieve a viable system.

Successfully scheduling airlift missions or FWMS shipments requires a variety of planning and scheduling models. These models should include rapid, high-level estimators of system capabilities to give planners and management an immediate answer to questions about resource needs and facility capabilities for handling a particular shipping campaign scenario. A flow scheduler would be used to generate detailed schedules for large-scale campaigns between a number of different facilities (i.e., reactors, MRS, Cask Maintenance Facility, and permanent repository). A schedule editor would be used to create individual schedules and edit those generated earlier by the flow scheduler or editor. A channel scheduler would schedule the same shipment over the same route in a sequence of time periods (i.e., daily or weekly). This set of tools would enable the long-range planners to develop "what if" scenarios and test them. Such planning could include various locations for facilities, amounts of spent nuclear fuel to be shipped, modes of shipment, and times and routes for shipping campaigns. Day-to-day shipping schedules could also be developed and modified with this set of tools.

Graphical interfaces are very useful in helping the user to evaluate large amounts of information very quickly. Graphical information can be used in the evaluation of available resources, amount and type of spent nuclear fuel to be shipped, and resulting schedules that have been generated.

VII. CONCLUSIONS

This paper has discussed the feasibility of using the concepts and tools that were developed for the military's transportation management systems in the FWMS Transportation System. Many of the lessons learned in the development of the planning and scheduling software for the U.S. military can be applied to the development of a similar planning and scheduling software for the FWMS Transportation System. The resulting system would be invaluable to OCRWM both initially, for long-range planning, and later, in day-to-day scheduling and management of the FWMS Transportation System.

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Table 1. Comparison Between Features of a Military and the FWMS Transportation Systems

Feature	Airlift Deployment	FWMS Transportation System
Facilities, Locations	Air Stations	Reactor Sites (by modal capability), Receiving Sites, Maintenance Facility(ies), Intermodal Transfer Points, and In-Transit Stopping Points
Routes	Air Routes	Road Routes, Rail Routes, and Barge Routes
Equipment	Aircraft	Casks, Ancillary Equipment, Spares, Baskets, Transporters, and Transportation Vehicles
Cargo	Cargo and Passengers	Spent Nuclear Fuel and High-Level Waste
Personnel	Air Crews	Transportation System Operations Personnel, including Field Operations, Cask Maintenance Facility, Operations Control Center, Drivers, Trainers, Emergency Response, etc.

Table 2. Comparison of Typical Airlift and FWMS Transportation System Shipments

Airlift Deployment	FWMS Transportation System Shipments
Cargo pickup/delivery scheduled	Cask contents pickup/delivery scheduled
Flight plans developed	Carriage plans developed
Aircraft identified/committed	Cask/transporter identified/ committed
Aircraft crews identified/ committed	Field operations and transport personnel identified/committed
Aircraft moved from home base to loading base	Cask system transported to shipping facility
Cargo and passengers loaded	Spent nuclear fuel loaded into cask
Loaded aircraft readied for flight	Cask loaded on skid; skid with cask transferred to heavy-haul unit; unit readied for short trip to intermodal transfer point
Aircraft/crew flies to intermediate base, refuels, flies to second intermediate base	Heavy-haul carriage to intermodal transfer point; skid with cask transferred to rail car; originating railroad initiates rail shipment
Crew changes at second airbase; aircraft continues to destination	Rail carrier changes at intermediate rail transfer point; shipment continues to receiving facility
Crew rests a destination, aircraft unloaded	Rail crew departs destination; cask off-loaded and, after waiting in queue, unloaded of spent fuel
Aircraft maintained, prepared for return journey (including loading of cargo)	Cask system inspected, decontaminated as needed, prepared for return journey
Aircrew assigned, return flight initiated and completed	Rail carriers and heavy-haul carriers scheduled; cask system picked up; trip initiated and completed